



NATIONAL RADIO INSTITUTE

Certified Radio-Trician's Course

(REG. U. S. PAT. OFF.)



CAPACITY

No. 7FR

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Washington, D. C.

REGULARITY IS THE KEY TO RELIABILITY

A Personal Message from J. E. Smith

Physical fitness depends a great deal on the regularity of the bodily functions. Physicians tell us that we should eat our meals at regular hours, that we should set aside a certain period each day for exercise and recreation. In this way we attain our maximum health. Mental regularity is not so easily achieved, although it can be acquired. There are many disturbing influences. It is difficult to have a fixed time and place for study and then stick to it. But once it is accomplished, study is easier and more efficient.

Reliability is the direct result of regularity. The man who is regular in his habits can be depended upon. Others can predict what he will do and when he will do it. He can depend upon himself. Students fail to get their work done because they cannot rely upon themselves to study when the time comes. Make yourself regular to make yourself reliable. Mental and bodily regularity will go a long way in determining your success.

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WASHINGTON, D. C.

Capacity

The meaning of the word "capacity" as it is commonly used, is familiar to all of us. We talk about the capacity of a tank, the capacity of a freight car. In Radio we talk about the capacity of a *condenser*—that is, how much electricity a condenser can hold.

In Radio circuits, *condensers* play as important a part as the inductance coils, in fact, the two are nearly always used together. Condensers are of two main types—*fixed* and *variable*. Fixed condensers, used for by-passing Radio frequency currents, for blocking direct currents, as grid condensers, as coupling condensers, etc., have a constant capacity. The variable condensers used for tuning, balancing, controlling regeneration, etc., are arranged so that their capacity may be varied.

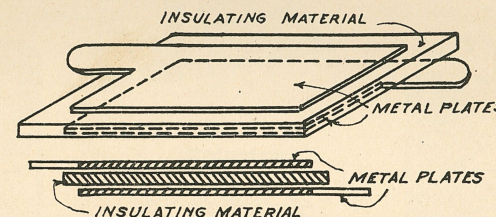


Fig. 1—Constructional Details of a Simple Condenser.

The constructional details of a simple fixed condenser are shown in Fig. 1. It consists essentially of two metallic parallel plates, generally made of tinfoil, copper or aluminum sheets separated by an *insulating* medium known as the *dielectric* of the condenser, which may be glass, mica, celluloid, oil, waxed paper or even air. Various types of commercial fixed condensers are shown in Fig. 2.

A typical variable condenser is shown in Fig. 3. This type of condenser consists of two sets of plates, one stationary (called the "stator") and the other rotating (called the "rotor"). The rotor plates interleaf between the fixed plates.

The capacity is varied by rotating the movable plates.

These condensers are used in Radio circuits where the capacity must be changed to allow us to obtain certain desired effects while the receiving set is in operation.

Condensers are by no means strange devices to most of us, and Figs. 1, 2, and 3 recall them to us. Condensers as capacities, "storerooms" for electricity is a new idea. What do we mean by storing electricity? We can store sugar in a barrel and gasoline in a tank. We realize these facts easily because we can actually see sugar, water and gasoline. In the same way we can store (charge) a condenser with electrons, actual little particles of electricity. Try to form a mental picture of these electrons, that really exist.



Fig. 2—Various Types of Fixed Condensers.

In any conductor millions of electrons are roaming around freely, held in the conductor by positive charges which prevent them, so to speak, from spilling out. Yet they can be withdrawn.

Figure 4 shows a water tank filled with water. Water is prevented from flowing out by a stop cock V. Should we open the valve V, the water will flow out. Place the palm of your hand under the valve and open it—a large force will push down on your hand. There is a force, a pressure, pushing the water out.

Take a large metallic ball; set it on an insulated stick and connect it to the ground through a wire W in which there is an electric valve S (a switch). (See Fig. 5.) In this case we open the switch S and electrons are stored in the ball. (How this is done will be explained shortly.) How can we prove that electricity is stored in it? Place little pieces of tissue paper on

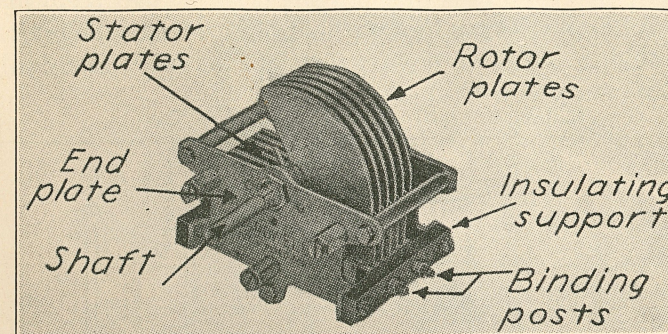


Fig. 3—Variable Condenser.

it and they will be shot off. Has it a pressure? Yes. Place a voltmeter across the open switch and a voltage (electrical pressure) will be indicated. Close the switch and the electrons will leak off to the ground.

In both cases, however, the stored material has been scattered so that it cannot be put to any good use.

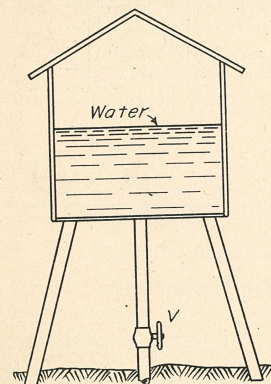


Fig. 4

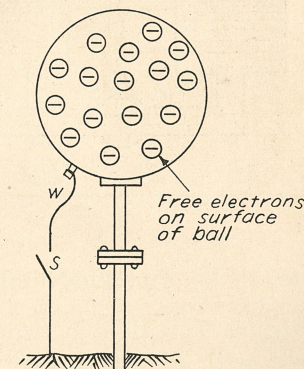


Fig. 5

Figure 6(a) shows two water tanks connected together, the left-hand tank A is filled with water which is prevented from flowing into B by the valve V. Open the valve and a current of water will flow in the pipe and B will fill up until there is an equal amount of water in each tank.

Compare this with 6(b), two metal plates, close together, but insulated from each other by the open switch S. Note that plate A is charged, it has twice as many negative electrons as positive charges, while plate B has been robbed of half its electrons. Close the switch and the extra negative electrons will divide themselves equally between the two plates. In this rearrangement electrons flow through the conductor C from plate A to plate B. Don't forget that we said before that when electrons flow through a wire, we have a flow of current. The final conditions are shown in 6(c) and 6(d).

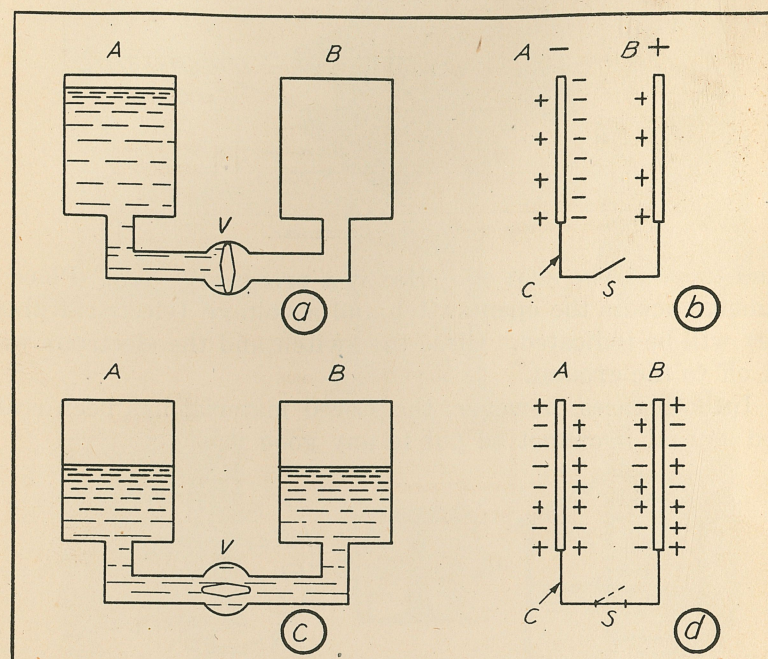


Fig. 6

ACTION OF A CONDENSER

Figure 7 will help us get an idea of how a condenser is charged with direct current. The upper electric circuit to the right of the diagram shows a battery connected to a condenser, but the circuit is incomplete because the switch is open. To the left is a tank connected to a rotary water pump and the tank is divided in the middle by a water-tight rubber diaphragm stretched across it. Obviously this divides the tank into two portions and as the pump is rotated in the counter clockwise

direction, water is withdrawn from compartment "A" and forced into compartment "B." This is clearly brought out in the sketch below which really indicates that the diaphragm has been stretched, a force has been exerted on it. In a sense we can say that the tank has been charged, because if no more mechanical energy was applied to the pump, the diaphragm would force the water back through the pump causing it to rotate in the opposite direction, therefore, delivering power and leveling the water in compartment "A."

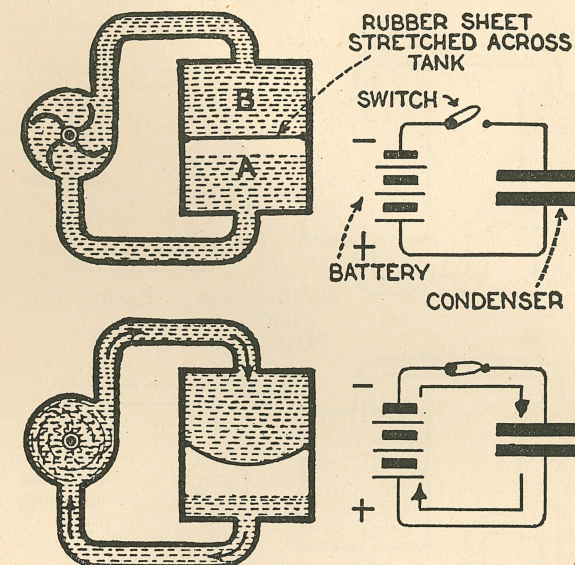


Fig. 7—Hydraulic Analogy Showing How a Condenser is Charged With Direct Current.

Let us see how close this is to the electrical condition in which we are vitally interested. But first let us review a few of the fundamental electrical concepts. We understand that a condenser consists of metal plates separated by insulating material, and both plates ordinarily have an equal amount of positive and negative charges and the positive, we must understand, cannot be separated from the metal plates. Then let us get a clear picture of what we mean by a battery and particularly, what we mean by saying that it develops an e.m.f. A source of e.m.f. is really nothing more than an electrical pump which has a positive and negative terminal. The positive terminal has the electrical property of drawing electrons to it. The negative side has the property of delivering electrons to a circuit. Therefore, in

Fig. 7 we have a battery with a positive terminal ready to draw electrons out of the lower plate of the condenser and a negative terminal from which electrons are forced into the upper plate. The diagram below shows this clearly. The lower side of the condenser is robbed of electrons and these are returned to the upper side. (This explains how the metal ball was charged in the previous discussion; an e.m.f. was connected between the ball and the switch, and the latter closed for a moment until the ball was charged to the limit of its capacity.)

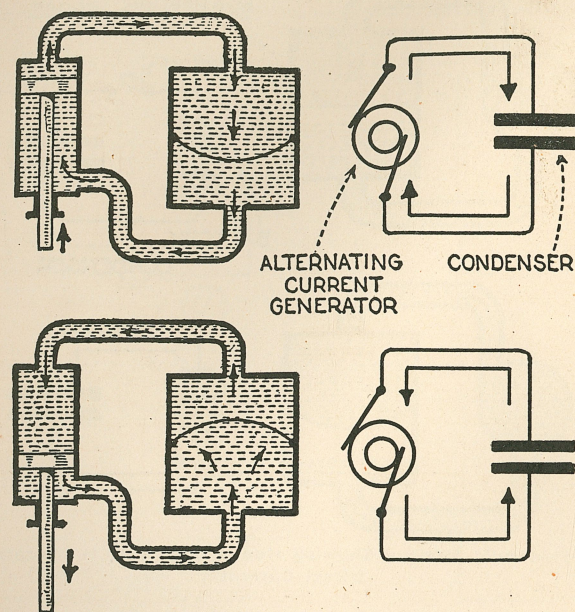


Fig. 8—Hydraulic Analogy Illustrating the Flow of Alternating Current Through a Condenser.

When the e.m.f. or battery is removed the electrical power stored in the condenser can be used, just as the charge in the water tank in Fig. 7 was used to turn the pump backwards.

If we increase the diameter and length of the tank, we can increase the amount of water it can store. This naturally increases the surface area of the tank. If a large amount of water is to be stored, we use a tank with a large surface area. Now the chief purpose of a condenser is to store electrical energy; therefore, we can see that the greater the surface area of the plates, the more electrical energy can be stored.

It is impracticable, for many reasons, to use condensers which have very large plates. To obtain a large capacity for Radio work, it is necessary to construct the condenser of several plates connected as shown in Fig. 3. This amounts to the same thing as having fewer plates with larger surface areas.

CHARGING A CONDENSER

Now, let us consider how a *simple condenser* can be charged using the circuit and apparatus shown in Fig. 9. When the plates of a condenser are connected by means of a metallic conductor to a battery, or some other source of constant e.m.f., a certain difference of potential (one plate will be negatively charged and the other we say is positively charged) will be established between the two plates. When the switch "S" is

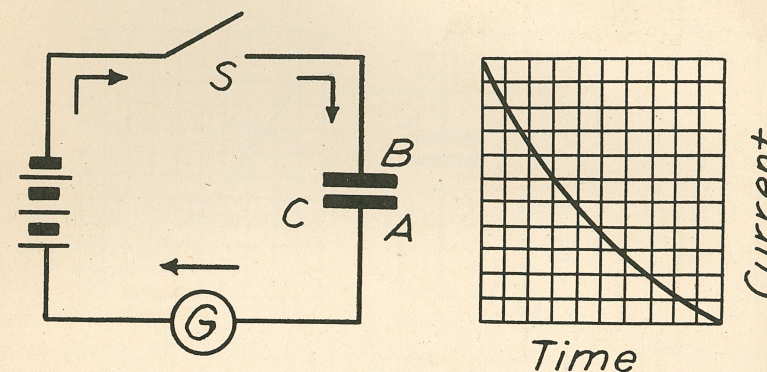


Fig. 9

closed, it will be found that a momentary current will flow, which will be indicated by the needle of the galvanometer "G," an instrument which indicates the presence of very small electric currents. But this current will soon stop flowing even though the battery still has an e.m.f. of 6 volts. You must realize that 6 volts can only withdraw from one condenser plate a definite amount of electrons. When the negative side of the condenser is charged to a point where the difference of potential between it and the other plate is 6 volts, charging stops, that is, no current will flow from the battery.

This stopping of current shows that the condenser has developed an electromotive force equal, but opposite to the applied e.m.f. In order that the difference of potential (an e.m.f.) exist between plates "A" and "B," the electrons in the circuit

must have been redistributed; that is, a certain number of electrons was removed from the positive plate "A" and a like number deposited on the negative plate "B." The transfer of these electrons, from one plate of the condenser to the other plate, is effected through the metallic circuit in which the battery is connected. The battery acts as a pump, drawing the electrons off one plate of the condenser and forcing them onto the other plate.

During the time that this transfer of electrons is being effected, an electric current flows in the metallic circuit.

Thus, the plates of the condenser become *charged* with electricity of opposite polarities, the plate carrying the excess of electrons acquiring a *negative charge* while the one from which they are removed acquires a *positive charge*. Furthermore, an electric field is established between the plates which acts in

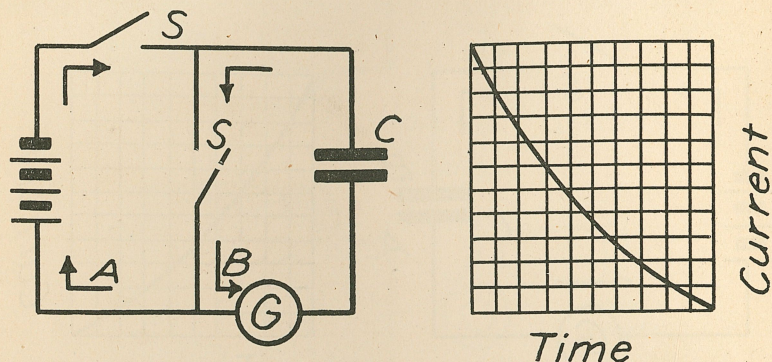


Fig. 10

opposition to the electromotive force of the battery. If the switch "S" is opened and a voltmeter applied to "A" and "B" it will be found that the condenser has an e.m.f. which is the result of the charging.

It is obvious then, that if the two charged plates of the condenser were suddenly connected together by a metallic conductor, across the dielectric, a flow of electrons would take place from the negative to positive plate.

DISCHARGING A CONDENSER

In Fig. 10, we have connected to the previous circuit (Fig. 9) another switch "S-1." When switch "S" is closed and "S-1" is open, the plates of the condenser will receive a charge, the potential difference of which is the same as that of the battery. If switch "S" is then opened and "S-1" is closed, the gal-

vanometer "G" will indicate a flow of current, but in the opposite direction showing that the condenser is discharging. In other words, the difference in distribution of electrons of the condenser plates is being equalized by means of a current flow from one plate to the other.

The negative plate, now instead of receiving electrons, is losing electrons which explains why the current will flow in the opposite direction.

As was previously stated, the condenser when charged developed a back pressure in opposition to the electromotive force of the battery. At full charge it balances the applied e.m.f. and current flow stops. At the instant charging starts the amount of current is at maximum but it quickly tapers off to zero as shown by the graph in Fig. 9.

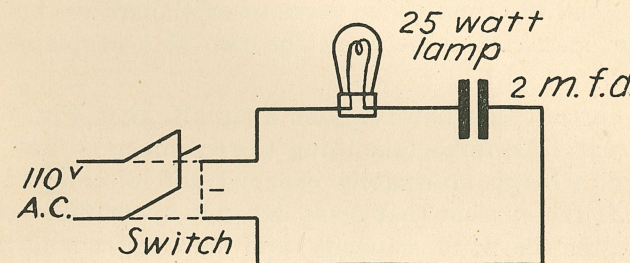


Fig. 11

Likewise when a condenser is discharged, the current flow is greatest at the instant of short-circuiting. This rapidly tapers off as shown by the graph in Fig. 10. Were it not for the resistance in the circuit, the condenser would discharge instantaneously. But because of this resistance, the current tapers off.

ALTERNATING CURRENT FLOW IN A CONDENSER CIRCUIT

The action of a condenser in an alternating current circuit is quite different from that of a direct current circuit.

This difference can be illustrated very easily by connecting a 2-mfd. capacity condenser in series with a 25-watt light bulb to a 110-volt alternating current lighting circuit. (See Fig. 11.) With this arrangement you will find that the bulb will light, but with the same arrangement on a direct current circuit it would not light, because the electrons are going in one direction and when the condenser is fully charged, it exerts a back e.m.f. which balances the applied e.m.f. and current flow stops.

There will, however, be a force urging the electrons to cross over from the negative plate to the positive plate but the insulation between the two sets of plates prevents them from going across.

When an *alternating current* is used the impressed e.m.f. continually rises in magnitude and changes in direction. The condenser is charged to the extent of the amplitude of one alternation. When the A.C. voltage reverses its direction, it charges the condenser in the opposite direction. Thus the plates of the condenser are alternately charged and discharged, when one is charged the other is positive and so on, following the alternations of the A.C. current.

This continual charging and discharging of the condenser allows a continual flow of electrons back and forth through the light bulb and the connecting wires, even though we have practically an open circuit between the two sets of plates of the condenser.

The current that flows in such a circuit, as in Fig. 11, is an A.C. current. An important thing to remember is that when a condenser is being alternately charged and discharged by an A.C. e.m.f., the current that flows depends upon the strength of the e.m.f., the size of the capacity, and the frequency of the A.C. The greater the frequency the greater the movement of electrons, that is, the flow of current.

OSCILLATORY CIRCUITS

We have now had an introduction to the three important quantities used in Radio receivers and transmitters, namely, *resistance*, *inductance*, and *capacity*. In many cases you will have all three connected together in series and the condenser charged. What will happen?

In Fig. 12 we have a capacity "C" in series with an inductance "L" and a resistance "R." The resistance "R" represents the direct current resistance of the inductance. It is never possible to have an inductance without having it contain some direct current resistance, and in order to bring out some of the fundamental principles, this direct current resistance is shown separately. The battery "B" is connected to this circuit by means of two switches "S" and "S-1." When "S-1" is open and "S" is closed, the battery e.m.f. will find a path through the resistance "R," the inductance "L," to the condenser "C," and in so doing,

the condenser "C" will gradually assume a charge until the potential difference between the two plates is equal to the potential of the battery. From our previous study, we have found that if a circuit is provided to discharge the condenser, it will gradually give off whatever charge it holds until its plates come to a state where no potential difference exists between the two.

Suppose we open switch "S-1" and close switch "S." The battery will gradually charge the condenser until it assumes a potential equal to that of the battery. Now by opening switch "S," the battery circuit is opened and the condenser remains in a charged position. Now let us close switch "S-1" so that a complete circuit is provided for the condenser to discharge. At the instant the switch "S-1" is closed, electrons rush out of one condenser plate in order to equalize the other. In proceeding through the circuit, the current passes through resistance "R" and inductance "L."

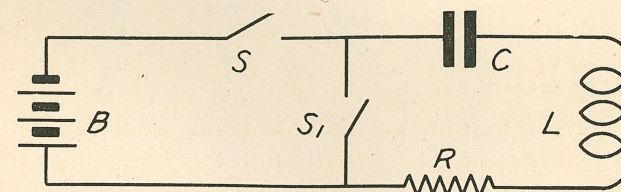


Fig. 12—Fundamental Oscillatory Circuit.

Naturally when current flows through the resistance power is lost, as we have already learned. This loss is equal to I^2R . On the other hand, the current in flowing through the inductance builds up a magnetic field around it, storing within it electrical magnetic energy. The result is that although the condenser charge has been neutralized the condenser no longer has a difference of potential, some of the energy of the condenser is stored in the inductance.

As the inductance cannot hold its magnetic energy after the condenser has lost its e.m.f., it naturally gives up its energy, which collapses on the wires, inducing an e.m.f. in the coil and this e.m.f. charges the condenser again but in the opposite direction. Of course, this is accompanied by a flow of current and more energy is lost in the resistance, in the form of an I^2R loss.

Then the condenser discharges again in an attempt to equalize the electrons on the two plates and again energy is lost

in the resistance. But enough energy remains to create a magnetic field about the inductance. This magnetic field is of opposite polarity but, nevertheless, energy is stored. When the condenser has given up all of its energy the inductance proceeds as before, its magnetic field collapses on it, and delivers an e.m.f., which charges the condenser in the original condition but much less than previously because of the I^2R losses.

The process continues and with every charge and discharge of the condenser, power is lost in the resistance and the quantity of electricity stored becomes less and less.

You can get the idea a little better perhaps by looking at Fig. 13. This illustration shows a heavy weight hung on a spring in a normal position of rest O. Suppose we pull the weight down and let go. What happens? When we let go, the

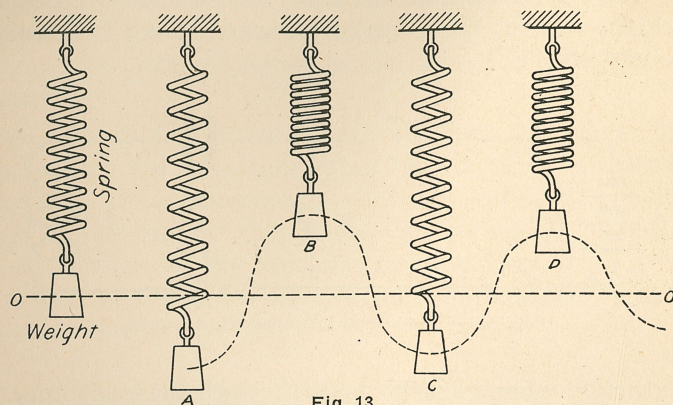
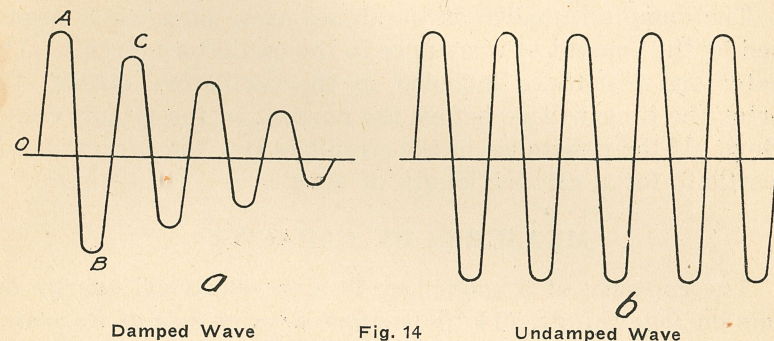


Fig. 13

weight is in the position A. The spring then pulls the weight upward until it reaches the point B, then the weight falls down again below the original position O to the position C. You will notice that position C is not as low as position A. The spring then pulls it upward again to the position D. The weight thus oscillates up and down with a decrease in its amplitude during each oscillation. Now let us consider in detail what goes on during this oscillation.

When we pulled the weight down we had to exert a certain force, and this produced a tension in the spring, due to our stretching it. Therefore, energy was put into the spring. Now, when we let go of the weight, the tension or energy in the spring pulls up the weight. In pulling up the weight, the spring gives up all of its energy, excepting a small part, to the weight. The energy which the weight does not receive is lost in friction with

the air. The weight finally gets to the top of its journey and no longer moves upward. It is clear that since the spring no longer pulls the weight upward that it has lost all of its energy. Where has this energy gone? The answer is, all the energy that was not lost in friction has been given to the weight. It is clear that this must be so, for at that instant the weight begins to move downward. In moving down, the weight gradually returns its energy to the spring by stretching it, for soon the weight stops moving downward as the spring is stretched to its limit and then moves upward again, repeating the whole process of transferring energy from one place to another. But gradually the system oscillates with decreased amplitude until finally it comes to rest, after all the energy in the system has been used up in friction with the air.



The coil and condenser act in a very similar manner, as we have seen. The energy in the spring may be likened to the charge (or voltage) of the condenser. The coil takes the part of the weight. The up and down motion of the spring and weight is like the to and fro motion of the electrons in the electric circuit.

If we were to place an oscilloscope, such as we have described before, into the circuit, Fig. 12, we could get a picture of the flow of current and it would appear exactly like Fig. 14(a). Such a variation of current is referred to as an oscillation, and in this particular case, as a *damped wave* oscillation because the oscillations die off rapidly. Of course, it is not really a wave. It is nothing more than a picture of current variations as they would appear if we watched them through the oscilloscope. You will learn later how rapid oscillations produce electromagnetic waves which we know are Radio waves. Although we refer to these as waves, to be absolutely correct we should

talk about them as damped wave current oscillations, for they are really in current form.

If we were to remove the resistance "R" from the circuit in Fig. 12 (which, by the way, would be impossible, as we could not build a capacity "C" or inductance "L" without some resistance) we would find that no energy would be lost in the successive discharges of the condenser and we would have what is known as an undamped current oscillation, as shown in Fig. 14(b). More often we call this particular variation in current a continuous wave oscillation. Just how we can obtain an effect equivalent to removing R we shall learn later. No doubt, you have heard the word C. W. transmitter. It is the continuous wave transmitter that is used in all broadcasting stations and in all modern Radiotelegraph transmitters.

The damping quality or the dying away of a wave is governed by the amount of resistance in the oscillatory circuit. The greater the resistance included in the oscillatory circuit, the shorter the time will be before the current in the circuit ceases to flow. If the resistance in the circuit is low, the current tends to oscillate for a greater length of time.

MEASURES OF CAPACITY

The capacity of a condenser to store electrical energy depends on four things, (1) the surface area or size of its plates, (2) the number of plates in the condenser, (3) the separation of the plates or thickness of the dielectric (insulation) between them, and (4) the substance used for the dielectric between the plates.

It would seem that a very thin dielectric would give the best results. This is true as long as the material is not so thin that its dielectric strength will break down and a discharge take place through it.

This can best be explained by a comparison with some simple arrangement as that shown in Fig. 15. This consists of two small balloons, connected to a gas jet from which they are filled or charged, if you wish, with gas. The two balloons in this illustration are of the same size, but one is made of thick rubber and the other of thin rubber.

A constant pressure is forced through the valves in the pipe but you see that the thin balloon has expanded perhaps to twice the size of the thick rubber balloon, yet both have been fed by the same pressure. By "pressure" here is meant the

tendency of the gas to force its way against the sides of the rubber and to expand it.

We might increase the pressure and both balloons would increase in size, but suddenly the thin balloon would break, whereas the thick rubber balloon could withstand even a greater pressure than that at which the thin balloon exploded. Of course, we might increase the pressure on this balloon until it also would break down. In other words, each balloon has a break-down pressure above which it will not resist the forces attempting to tear it apart. Naturally the safe pressure to which these balloons can be subjected to, will be somewhat less than the break-down pressure.

We may even try another experiment with balloons, in which case a small and a large balloon of the same thickness are employed. We would find that the volume of the large balloon

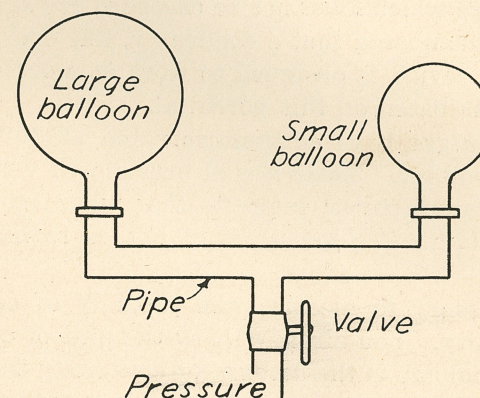


Fig. 15

would always be greater than that of the small one. But more than likely we would find that both balloons would break at the same pressure.

We have very similar conditions in Radio circuits. Two condensers may have metallic plates of equal surfaces but if one has a thicker dielectric than the other, the former would not store as much capacity as the one with a thin dielectric, and at the same time the condenser having a thin dielectric would not stand as high an electrical pressure (e.m.f.), as the condenser having the thick dielectric. It would not be as safe to operate the thin dielectric condenser on heavy voltages. Condensers are always rated at working voltages, which means a safe voltage which the condenser can stand continuously without danger of break-

ing down. The farther it is charged with a voltage above that value, the more unsafe it becomes and the more likelihood that it will break down, and become worthless. Likewise, if two condensers both have the same dielectric thickness but one has a greater surface area, this one would naturally have the greater capacity for storing electricity.

Electrically, if we apply a greater voltage we draw more electrons out of the one plate and put more into the other one. Naturally the electrons on one side of the plate tend to force their way through the dielectric, in order to get onto the other plate and if the difference in the number of electrons is great enough, they will actually break through the dielectric.

Let us sum up what we have learned. The thinner the dielectric, the greater the capacity is; the greater the area of plates, the greater the capacity. Every condenser has a critical charging voltage which must not be exceeded for safe operation. It should be remembered that a condenser, like every other electrical or Radio device, is designed to work at a certain potential and its rating is based on this potential.

Thus we might have condensers rated at 300 volts, their safe working voltage. Their actual breakdown voltage may be 400, yet the manufacturer suggests that where voltages above 300 are to be handled, condensers of higher ratings should be used.

It is necessary to measure the capacity of condensers in terms of quantity. You already know the unit of quantity—the coulomb. A coulomb is the *amount* of electricity that flows past a single point during one second of time in a conductor through which one ampere of current is flowing. When a condenser requires a charge of one coulomb to bring its plates to a potential difference of one volt, it is said to have a capacity of *one Farad*. But this unit is too large for ordinary purposes. The microfarad (one millionth of a farad) is the practical unit of capacity. Even smaller values of capacity are used in Radio circuits and these are expressed in milli-microfarads (thousandth of a microfarad) and in micro-microfarads (millionths of a microfarad). It is more common, however, to designate the capacities of condensers used in Radio circuits in decimal fractions of a microfarad. Thus, 1 milli-microfarad is commonly expressed as .001 mfd. (microfarad).

A condenser of .001 mfd. requires a charge of one billionth of a coulomb to charge it to a potential of one volt. In

other words, since a current of one ampere represents one coulomb per second, a current of one ampere would have to flow for only one billionth of a second to charge a perfect .001 mfd. condenser to a potential of one volt; or similarly, if a current of

TABLE NO. I

Number of Plates in Condenser	Maximum Capacity of Con- denser in Microfarads
13	.00025
17	.00035
23	.00050
43	.001

one milli-microampere flows for one second, it will charge the condenser to a potential of one volt.

Expressed in a formula, the relation between capacity (C), quantity (Q) and potential (E) is as follows:

$$C = \frac{Q}{E}; \quad Q = CE; \quad \text{or } E = \frac{Q}{C}$$

Variable air condensers (having air dielectrics) used for tuning Radio circuits are often rated by the total number of their

TABLE NO. II

Material	Dielectric Constant
Air	1
Rubber	2 to 3
Paraffin	2 to 4
Shellac	2.5 to 3.5
Mica	2.5 to 8
Glass	4 to 10
Slate	6 to 7
Porcelain	3 to 6
Paper	1.5 to 3

plates; that is, a condenser with six rotor plates and seven stator plates would be rated as a thirteen-plate condenser. Commercial types of variable air condensers are usually of the sizes given in Table No. 1, and their capacity is approximately as indicated.

It is a common expression among Radio men to say double O one, triple O five, triple O two five, meaning condensers of .001, .0005, .00025 of a microfarad.

DIELECTRIC CONSTANT

Reference has been made several times to the material used for the dielectric in condensers. Different materials influence the capacity of a condenser to a very marked extent. The dielectric constant of any material is equal to the ratio of the capacity of a condenser using the particular material as a dielectric, to the capacity of the same condenser using air as a dielectric taken as the standard of one (1). Table No. II gives the dielectric constants for various materials.

Table No. II shows that if any material other than air is used as a dielectric in fixed condensers they can be made more compact for a given capacity than if air were used. A formula for calculating the capacity of a condenser, having two parallel plates of the same shape and size is as follows:

$$C = 0.0885 \frac{K S}{t} \quad (1)$$

Where

C = Capacity in micro-microfarads.
K = Dielectric Constant.
S = Surface area of one side of one plate in square centimeters.
t = Thickness of dielectric in centimeters (one inch = 2.53 centimeters).
.0885 = A constant used—determined by experiment.

When a condenser is composed of several parallel plates, the following formula will determine its capacity.

$$C = .0885 \frac{K (n - 1) S}{t} \quad (2)$$

Where

C = Capacity in micro-microfarads.
K = Dielectric Constant.
S = Area of one side of one condenser plate in square centimeters.
t = Thickness of the dielectric material in centimeters.
n = Total number of plates—I

For example, suppose we have a 23-plate condenser each plate having an area on one side of 12 square centimeters and with a

separation of 0.05 centimeter between the plates. Dielectric is air having a constant of 1.

$$C = 0.0885 \times \frac{1 \times (23-1) \times 12}{0.05} \\ = 467 \text{ mmf. or } .00047 \text{ mfd. (approximately).}$$

CAPACITIES IN PARALLEL AND IN SERIES

Not always do we use individual condensers but quite often condensers, like inductances and batteries, are connected in series or parallel and consequently, we are interested in the total capacity of the arrangement.

When condensers are connected in parallel we have a very simple formula, that is, the total capacity is equal to the sum of the individual capacities. Thus,

$$C = C_1 + C_2 + C_3 + C_4 \text{ etc.} \quad (3)$$

For example four condensers having respectively .03, .07, .092, .001 mfd. are connected in parallel. The total is

$$C = .03 + .07 + .092 + .001 = .193 \text{ mfd.}$$

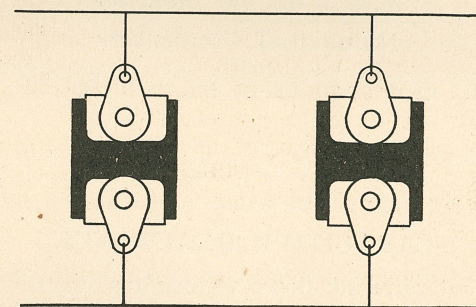


Fig. 16—Condensers Connected in Parallel.

The simplest case is where the condensers in parallel are of the same size and the rule is the total capacity equals the number of condensers times the capacity of one condenser. That is,

$$C = N \times C_1 \quad (3a)$$

Should condensers be connected in series, the following formula is applied:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \text{ etc.} \quad (4)$$

For example, if the above condensers were connected in series, the total capacity would be:

$$C = \frac{1}{\frac{1}{.03} + \frac{1}{.07} + \frac{1}{.092} + \frac{1}{.001}} \quad (4a)$$

$$= \frac{1}{33.3 + 14.3 + 10.9 + 1000}$$

$$= \frac{1}{1058} = .00095 \text{ mfd.}$$

Notice that the total capacity of a series arrangement is always less than the smallest capacity.

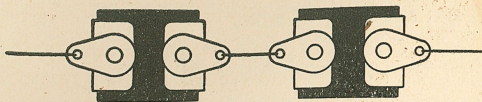


Fig. 17—Condensers Connected in Series.

The simplest case is when all capacities are equal, in which case

$$C = \frac{\text{Capacity of one Condenser}}{\text{Number of Condensers}} \quad (5)$$

Thus, if four .01 mfd. condensers are in series, the final capacity will be

$$\frac{.01}{4} = .0025 \text{ mfd.}$$

CAPACITIVE REACTANCE

When direct current flows through a circuit it is opposed only by the resistance of the circuit; but when alternating current flows it is opposed by both the resistance and the A.C. opposition, called the reactance, of the capacities and the inductances in the circuit. In a previous lesson we studied inductive reactance and its effect in a circuit. Condensers offer *capacitive reactance* to A.C. current flow. But the effect of capacitive reactance is directly the reverse of the effect of inductive reactance.

You remember that inductance in an A.C. circuit caused the voltage to lead the current—they were out of phase. Capacitive reactance causes the current to lead the voltage or we can say the voltage lags behind the current. A circuit with a coil in it is thrown out of phase because of the magnetic field which is set

up about the coil and the prolongation of current flow due to the collapse of the field. A circuit with a condenser in it is thrown out of phase by the *back* e.m.f. which opposes current flow. This back e.m.f. reduces the effect of the applied e.m.f., causing the current to use to maximum value before the voltage reaches maximum value.

Reactance, as stated before, is the name given to the opposition to flow of alternating current when this opposition is caused by the inductance of a coil, or by the capacity of a condenser. Reactance is measured in *ohms*. The total opposition to the passage of an alternating current through a circuit is called *impedance*. Reactance is called the reactive component of the circuit impedance. Reactance caused by the capacity of a condenser is called *capacitive reactance*. Either kind of reactance may act to hinder or aid the flow of alternating current. *Inductive reactance, the reactance of a coil, increases with the increase of frequency and is often called positive reactance. Capacitive reactance, the reactance of a condenser, grows less with increase of frequency, and is often called negative reactance.* The values of inductive reactance may be preceded by the positive sign (+), while the value of capacitive reactance may be preceded by the negative sign (—). When the frequency is measured in kilocycles and the inductance in millihenries, the inductive reactance in ohms is as follows:

$$\text{Inductive reactance} = 6.28 \times \text{frequency} \times \text{inductance} \quad (6)$$

The same formula holds true when the frequency is measured in cycles, and the inductance in henries.

The number 6.28 is the approximate value of 2π , the Greek letter which stands for the ratio of a circle circumference to its diameter. When the frequency is measured in cycles and the capacity in microfarads, the capacitive reactance in ohms is found by dividing 159,000 by the frequency in cycles times the capacity in microfarads.

$$\text{Capacitive Reactance} = \frac{159,000}{\text{Frequency} \times \text{Capacity}} \quad (7)$$

159,000 is a constant which was determined by experience.

If the inductive reactance which is considered as a positive quality just equals the capacitive reactance which is considered a negative quality, the two will balance each other and no effective reactance will be left in the circuit, provided they are in

series. The only opposition then remaining to the flow of alternating current at the particular frequency being considered is the resistance, and the circuit is said to be in resonance with that frequency.

To a direct current, a condenser has extremely high resistance. In fact, to direct current, whose voltage is not great enough to break through the dielectric, the condenser offers an infinitely high resistance—it acts as a break in the circuit. A condenser does not offer this infinitely high resistance to alternating current, but offers only reactance. Here again, the reactance does not cause a loss of energy but stores it on the plates of the condenser in the form of electric charges which will return the energy to the circuit.

To an alternating current of given frequency, a large condenser has less reactance than a small one and the larger the capacity of the condenser, the less is its reactance at a given frequency.

In an alternating current circuit a condenser having definite capacity will have less reactance at a higher frequency than the same capacity at a lower frequency.

To bring this out more clearly, suppose we have a condenser of 1 mfd. capacity and we desire to determine its reactance when placed in a 60-cycle circuit.

$$\text{Capacity Reactance} = \frac{159,000}{60 \times 1} \quad \text{or}$$

approximately 2650 ohms, the reactance.

Now suppose that this 1 mfd. condenser was inserted in an alternating current circuit, the frequency of which was 3,000 cycles. Solving this formula, we find that the reactance at a frequency of 3,000 cycles is approximately 53 ohms.

$$\text{Capacity Reactance} = \frac{159,000}{3000 \times 1} \quad \text{or } 53 \text{ ohms.}$$

PHASE RELATION OF VOLTAGE AND CURRENT IN A.C. CIRCUITS

The phase difference between a voltage and a current in an alternating current circuit has been defined as the time difference between their amplitudes. The voltage rises and falls, going through all values from maximum in one direction to maximum in the opposite direction.

The current resulting from the alternating voltage goes through corresponding changes. If the two are in phase, that is, if the phase difference between them is zero, the maximum value of the current occurs at the same time as the maximum value of the voltage. Also the two are zero at the same time. When there is a phase difference the current may reach a certain value either before or after the corresponding value of the voltage.

In other words there are *three* possible relations that may exist between the current and the voltage which causes the flow:

First, as explained in a previous lesson, the voltage and the current may be in phase with one another, that is to say, they may be acting in unison with each other.

This is well illustrated by Fig. 18. The e.m.f. or (voltage) is shown by the heavy curved line *E* while the current is repre-

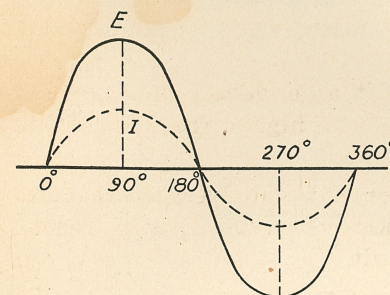


Fig. 18

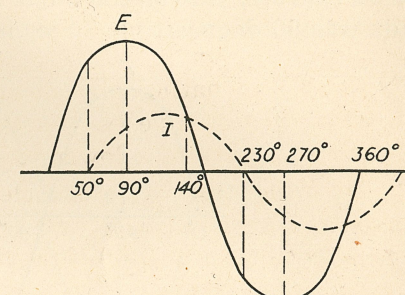


Fig. 19

sented by the light curved line *I*. Notice that the current and pressure reach a maximum value at 90 degrees and both decrease to zero at 180 degrees. The same changes occur when the pressure is exerted in the opposite direction and both continue to change in this manner for each cycle that takes place in the circuit.

The second possible relation is where the current lags behind the pressure. This is caused by the presence of inductance in a circuit. (Inductance is the property of an electric circuit which opposes a change in current.) This is illustrated by the curves shown in Fig. 19. Notice that the current is zero *after* the pressure has increased to a value of nearly three-fourths of its maximum value; that is to say, when the pressure is maximum the current has reached about one-half its maximum value and by the time the pressure begins to die down to about one-half its maximum value, the current has reached its maximum value.

Follow these two curves throughout the cycle and familiarize yourself with the relations existing between them in a circuit containing inductance.

If it were possible to have a circuit with pure inductance alone, with no resistance or capacity, the current would lag 90 degrees behind the pressure at all times. (See Fig. 20.) If you stop and think for a moment you will see that when the pressure is maximum the current would be zero and according to that we would have practically no power in the circuit.

The third possible relation is where the current leads the pressure. This is illustrated in Fig. 21. These curves are for a circuit containing capacity alone without resistance.

If it were possible to have a circuit with pure capacity alone, with no resistance or inductance, the angle of lead would be 90 degrees, just as the angle of lag in a purely inductive circuit was 90 degrees.

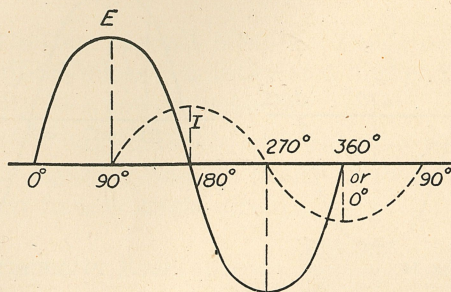


Fig. 20

A circuit, however, which contains capacity only is just as impossible as a circuit which contains inductance only.

There is always some resistance in any circuit. When we have resistance in addition to capacity, the angle of lead is smaller than 90 degrees. Consequently useful power can be obtained from a circuit which includes capacity as was shown when the power in a capacitive A.C. circuit was used to light an electric bulb.

As previously mentioned, if there is an equal amount of inductive and capacitive reactance in a circuit the two will neutralize each other. Their effects are 180 degrees apart.

RESONANCE

You remember we stated in a previous paragraph that the flow of alternating current in a circuit is opposed by three things: The resistance, the inductive reactance and the capacitive reactance. The resistance is due to resistance of the various

conductors in the circuit and to the resistance of the connections between them. The total resistance may be reduced by using good conductors of the proper size, but resistance cannot be completely eliminated from any circuit. The inductive reactance depends on the inductance in the circuit—the greater the inductance in the coils and other parts, the greater the resultant inductive reactance. The capacitive reactance depends on the capacity of the condensers and other parts in the circuit. The greater the capacity, the less the capacitive reactance.

When we speak of adjusting the capacity and inductance to resonance, we refer to resonance at a certain frequency. When the inductive and capacitive reactances are equal and their effects are neutralized at any certain frequency the circuit is said to be in a state of resonance with that frequency. In a simple circuit containing inductance and capacity in series, at any given frequency, there are certain values of capacity and inductance

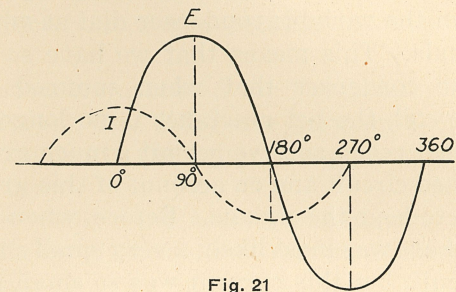


Fig. 21

which cause resonance at this frequency, but at no other frequency. If the frequency in the alternating current circuit should change, it would be necessary to make a different adjustment of either inductance or capacity in order that the resonant condition might again be obtained at the new frequency. This is why we must readjust dials for different stations. When the capacity and inductance are adjusted to balance each other at one certain frequency the maximum possible current at this frequency will then flow through the circuit, although currents of other frequencies still will be opposed by the reactances.

If the frequency is lowered, either the inductance, the capacity, or both, must be increased to maintain resonance. If the frequency is increased, then the capacity, the inductance, or both, must be decreased to maintain resonance. In other words, the greater the frequency the less must be the capacity and inductance, and the lower the frequency, the greater must be the capacity and inductance.

This is the principle of tuning a Radio receiving set to incoming signals, when we adjust the capacity of the variable condenser or vary the number of turns of wire on the tuning coil, or do both to make the reactance zero, or as near zero as possible.

In other words, when we tune a circuit like the ones we have in Radio receivers, we adjust the reactances so that their sum is zero. Generally, we do not vary the inductance (of the coil) but only adjust the capacity. That is why we always use variable condensers for tuning. Suppose we are trying to receive a signal which has a certain frequency; then, when the current due to the signal flows through the tuned circuit, the coil has a certain reactance to it, and the condenser likewise has a certain reactance to it. In general, this reactance will be enormous, perhaps thousands of ohms, but as we turn the variable condenser dial, we change the capacity of the condenser; we are at the same time changing its reactance to the incoming signal. Soon we find a position on the variable condenser dial at which we begin to hear the signals. This means that we have so adjusted the reactance of the condenser that when summed up with the reactance of the coil, the net reactance is no longer very great. In reducing the net reactance, we permit a much greater current to flow in the tuned circuit and on account of this greater current we are now able to hear the signals. Before, when the reactance was very high, there was most likely a very small current flowing in the tuned circuit, but this current was so small that we could not hear the signals properly.

Now, finally, as we continue to turn the variable condenser dial, we get to a position where the strength of the signals is greatest. This is the condition of resonance, as we call it; the circuits are now tuned to the same frequency as the frequency of the incoming signals. If we turn the condenser dial still farther, the signals will get weaker, indicating that the circuits are no longer in resonance.

It is clear, then, that there is one certain adjustment of the circuits when receiving signals of a certain frequency, which will result in the loudest signals. This is the condition of resonance as we have said, and is obtained when we make the net reactance of the circuit zero. We do this by making the inductive reactance at the coil, exactly equal to the capacitive reactance of the condenser, and since we have opposite algebraic signs (that is, one is plus and the other is minus), they sum up to zero. So now, in order to have resonance, we must have this:

Inductive reactance minus capacitive reactance equals zero. This is the same thing as saying that—

Inductive reactance equals the capacitive reactance. This is the most important thing that we have to learn in connection with tuning and tuned circuits. This relation gives you the principle of resonance, and if you get to understand it clearly, you will have little or no trouble in much of your study of Radio. You must first get into your mind the idea of what reactance is; after that, the idea of resonance comes easily enough.

TYPES AND NAMES OF RADIO CONDENSERS

All condensers function in the same way. The names applied to them indicate merely the particular uses to which they are put. For example, in Radio circuits, we have condensers which we call "fixed," "by-pass," "buffer," "tuning," "filter," "ganged." Then there are condensers such as "straight line" condensers, named from the peculiar manner in which they function.

Fixed condensers are used for "by-pass," "filter," "buffer" and other purposes, the difference between them being only a difference in size and in the voltage they are built to stand without breaking down.

For power pack work and in eliminators and filters connected to the lighting circuit, the important thing is the voltage breakdown test.

In Radio circuits, by-pass condensers have no great voltage strain on them because there is little voltage drop between the two ends of the coil which the condenser by-passes. The purpose of these condensers is to allow a path around the coil for Radio frequency currents which would be choked out by the coil.

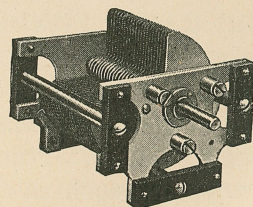
There are three types of variable tuning condensers, the *straight line capacity*, the *straight line wave* and the *straight line frequency*.

The straight line capacity variable condenser having semi-circular plates gives a comparatively uniform increase in capacity as the rotor plates are turned and intermeshed with the stator plates. A condenser of this type when used for tuning purposes with a fixed coil in a Radio receiver will not give a uniform increase in wavelength as the dial is turned from zero to maximum. If a graph is plotted with dial settings against capacity, it is a straight line.

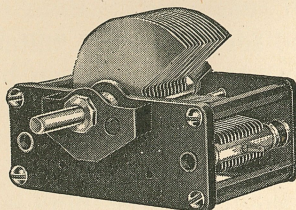
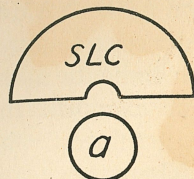
Therefore, since Broadcasting Stations are separated in fre-

quency by 10 kilocycles, it will take only a very small motion of the condenser dial to cover 10 kilocycles and go from one station to the next, at the lower end of the scale (high frequencies) which will crowd the stations together on the dial at the low wavelengths.

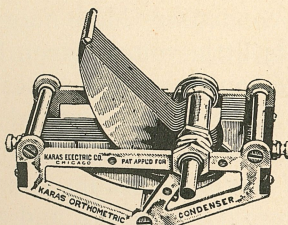
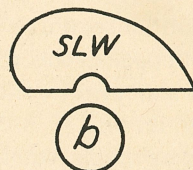
The straight line wave condenser is made by shaping the plates of the condenser so that the variation of the dial is proportional to the wavelength of the tuned circuit, that is, it does not give a uniform increase in capacity when varied, but does give a uniform increase in wavelength.



Straight Line Capacity Variable Condenser.

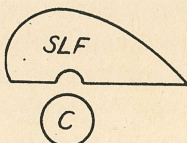


Straight Line Wavelength Variable Condenser.



Straight Line Frequency Variable Condenser.

Fig. 22



From the paragraphs above, it can be seen that SLC and SLW condensers are at a disadvantage when used for tuning circuits of broadcast receivers. However, they are useful in laboratory work, where equal increases of capacity or wavelength are desired.

Straight line frequency condensers are manufactured with plates shaped as shown in Fig. 22(c) which makes the rotation of dial proportional to the frequency of the tuned circuit. With

this type of condenser, stations separated by 10 kilocycles in frequency come in at equally separated points on the dial.

There are some variable condensers, as for instance, the "centraline," "midline," etc., which have irregular shaped plates which permit approximately SLF tuning at the low end of the dial, SLW tuning at the center region, and SLC tuning at the upper wavelengths.

In modern Radio receiving sets, three or four Radio frequency circuits are tuned by a single control. This means that three or four variable condensers must be grouped (ganged) together on the same shaft and the assembly is called a "ganged" condenser.

We have now come to the end of this lesson. Before you go on with the following lessons of this course, be sure you understand all that is in this lesson thoroughly.

The material contained in it is of utmost importance to you in your study of Radio, so study it hard and learn it well.

TEST QUESTIONS

Number Your Answer Sheet 7FR and add Your *Student Number*.

Never hold up a set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely, you'll get more out of your course and better lesson service.

1. Describe the construction of a small fixed condenser.
2. Give details of the construction of a variable condenser.
3. Explain the action of a condenser in an A.C. circuit.
4. Why do the oscillations finally die out in the discharge of a condenser through an inductance coil?
5. What factors does the capacity of a condenser depend upon?
6. In what units do we measure the capacity of Radio condensers?
7. Explain what is meant by dielectric constant.
8. What is the total capacity of two condensers connected in parallel each having a capacity of .002 microfarads?
9. When capacity is introduced into a circuit what effect has it upon the phase relation between current and voltage?
10. What term is used to denote that the Capacity and Inductance Reactance just balance each other?